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SHORT TIME TENSILE AND CREEP PROPERTIES OF COMMERCIALLY PURE TITANIUM AND THREE TITANIUM ALLOYS

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Engineering Laboratories

SHORT TIME TENSILE AND CREEP PROPERTIES OF COMMERCIALLY PURE TITANIUM AND THREE TITANIUM ALLOYS

Bell Laboratory Report

BLR 62-24 (M)

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ABSTRACT

This report presents data obtained for short time tensile and creep properties of commercially pure titanium (RC70) and three titanium alloys (MST 821, 6Al-4V, and B120VCA at 2500, 2250 and 2000°F.

It was determined from the data obtained that the material possessing the greatest strength at 2500°F is the titanium alloy B120VCA.

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I. INTRODUCTION

Short time tensile and creep properties of commercially pure titanium (RC 70) and three titanium alloys (MST 821, 6Al-4V, and B120VCA) were determined at 2500, 2250, and 2000°F for use in rocket motor designs, the high melting point of titanium (3150°F ± 150°F) being a primary consideration in its use for this application.

II. BACKGROUND

A. GENERAL

In order to obtain the temperatures asked for and to facilitate the measurement of strain, resistance heating of the sheet specimens was selected as the most economical method of obtaining the results presented herein.

The first attempt at heating a specimen of titanium was performed using a Lincoln d-c arc welder. Although it was possible to heat the specimens using the welder, further work indicated two problem areas: (1) control of the current and voltage was not as fine as desired; and (2) the d-c current and voltage induced into the specimen set up an electrical field which complicated temperature measurement. This electrical field induced a voltage into the spot welded thermocouple leads causing the recorder to indicate excessively high temperatures. Positioning of the thermocouple could prevent this error; however, the leads must be in good alignment. The positioning of thermocouple leads would have involved a cut and try method for each bar; thus involving a great deal of specimen preparation time.

B. HEATING

Due to the above problem areas it was decided to use one channel of a Westinghouse Ignitron Control Unit. Figure 1 is a block diagram of the circuitry used for these tests. Quartz pencil lamps, 48 per bank, connected in parallel were used as a resistive load with the specimen being connected in series with this load.

The frame of the testing machine was insulated by maple beams, insulation tubing, and sheet material around the connecting bolts and frame. Figures 2, 3 and 4 show the components used in the overall setup. The insulated areas of the testing frame are clearly visible in Figure 4. A check of the voltage breakdown of the frame was made prior to turning the power on with a Hypotter. The incorporation of the transformer, Figure 3, was done to further safeguard against the possibility of a shock hazard. Figure 5, the electrical schematic diagram of the system, shows this isolation transformer and its function in the circuit. Since there is an approximate 4 to 1 reduction from the primary to the secondary, it decreases the control potentiometer making it more effective over our operating range.

C. ENVIRONMENTAL CONDITIONS

Figure 6 is a close-up of the testing frame. All tests were carried out in a partial atmosphere of argon and air to simulate the service requirements. The exhaust gases of the motor tend to be reducing rather than oxidative. The retort used to contain the gas and test specimen is seen in Figure 6. Plexiglass enclosure sides were used in building the retort thus allowing the specimens to be visible during the test. A dew point indicator was used on each test to check the atmosphere which was maintained from -0°F to -13°F.

D. TEMPERATURE MEASUREMENT

Several methods of measuring the temperature of the specimen were tried, these were:

(1) Optical pyrometer
(2) Al_2O_3, bonded Pt. Pt. 10% Rh thermocouple
(3) Spotwelded Pt. Pt. 10% Rh thermocouple
(4) Spotwelded Cr Al Thermocouple

Of the methods listed, the one used was a spotwelded Pt. Pt. 10% Rh thermocouple. The original work statement called for tests at 3000°F. However, not one of the above methods with available laboratory equipment was found capable of measuring the temperature of the specimen within close thermal accuracy. The spotwelded Pt. Pt. 10% Rh thermocouple melted at 2900°F due to contamination, and rewelded itself at the edge of the specimen which was cooler than the center of the speciment, Figure 7. The optical pyrometer used had a very slow response and was difficult to calibrate due to changes occurring on the surface of the specimen resulting from a variance in surface oxidation from one specimen to another which affected the emissivity. The Al_2O_3 bonded Pt. Pt. 10% rhodium thermocouple was found to be incapable of measuring a true temperature as intimate surface contact did not exist. This type of thermocouple is very delicate to handle and required hours to prepare a test coupon. The spotwelded Cr Al thermocouples were difficult to calibrate as they had to be located in a cooler part of the specimen (+ 2500°F) and slight variances in the dimensions of the specimens make calibration difficult.

The tests were therefore limited to 2500°F due not to an inability to attain the high temperature, but due to the fact that 3000°F could not be measured with any degree of accuracy.

The reactivity of the metal we were working with played a predominate role in making temperature measurement difficult. The use of other noble metal thermocouples may have allowed us to measure the 3000°F temperature. The Instrumentation Laboratory of the Engineering Laboratories is aware of the problem encountered here and it is expected that in future programs the melting point of the material being tested will be attainable within engineering accuracy.

E. LOADING

Figure 8 is a block diagram of the servo system used to control the load during application to a tensile specimen. The load is applied by the hydraulic system, the loading arm of the jack passing through a Lempco bearing to the specimen. The bottom of the specimen is connected in series to a calibrated load cell mounted to the base of the loading frame.

Creep data was obtained using dead weight loading since the loads applied were small. Small cloth bags loaded with lead shot were mechanically attached to the specimen. It was necessary to use 1/2 pound "disk" weights in several tests of the B120VCA material due to the space available in the testing chamber for the suspension of the load.

F. STRAIN MEASUREMENT

The extensometer used in this work has been used extensively by Southern Research Institute. It is an instrument particularly adaptable to specimens which are resistance heated. The rigid contact arms were made from "Invar". These arms translate the elongation within the gage length of the specimen into flexure of the springs (Figure 6). Type SR-4 strain gages are mounted on both sides of the springs. The four strain gages are electrically connected in a bridge circuit. With two gages in tension and two gages in compression, all four strain gages in the extensometer bridge circuit function both for strain measurement and temperature compensation. The output of the extensometer is an electrical signal proportional to the average strain along the two edges of the specimen.

The free length of the extensometer is about 10 percent longer than the gage length of the specimen. To attach the extensometer to the specimen, the free ends of the contact arms are depressed sufficiently to insert between the protruding lugs on both sides of the specimen. The restoring force of the springs is small, yet sufficient to cause the extensometer to support itself between the lugs; hence the name, clip-on extensometer. As the tensile specimen is strained during testing, the springs relax proportionally.

Even though the electrical bridge circuit used in connecting the strain gages is temperature compensating, the extra precaution of monitoring the temperature of the strain gages was employed due to heat confinement brought about by the plexiglass enclosure chamber. Argon gas was passed over the gages in various quantities to maintain a temperature balance between the active arms of the bridge. Bakelite gages were used on the extensometer after experience was gained with the system and the magnitude of the temperature rise was measured. These gages are more stable at elevated temperatures than the plain foil gages.

G. SPECIMENS

The extremities of the two inch gage length of the specimens is marked by small extrusions in the plane of the sheet, Figure 9. These lugs served as points of contact for the extensometer. These small extrusions never reached the test temperature of the gage section.

H. DATA

The mechanical property data of commercially pure titanium, and the titanium alloys evaluated, MST 821; 6Al-4V, and B120VCA, is presented in Tables I, II, III, IV, V, and VI. The creep curves shown in Figures 10 and 11 are average plots of the creep data. All of the stress-strain curves are on file for reference in the Metallurgical Laboratory. The material possessing the greatest strength at 2500°F is B120VCA.

ACKNOWLEDGMENT

The cooperation of I. Depuy in this program is gratefully acknowledged.

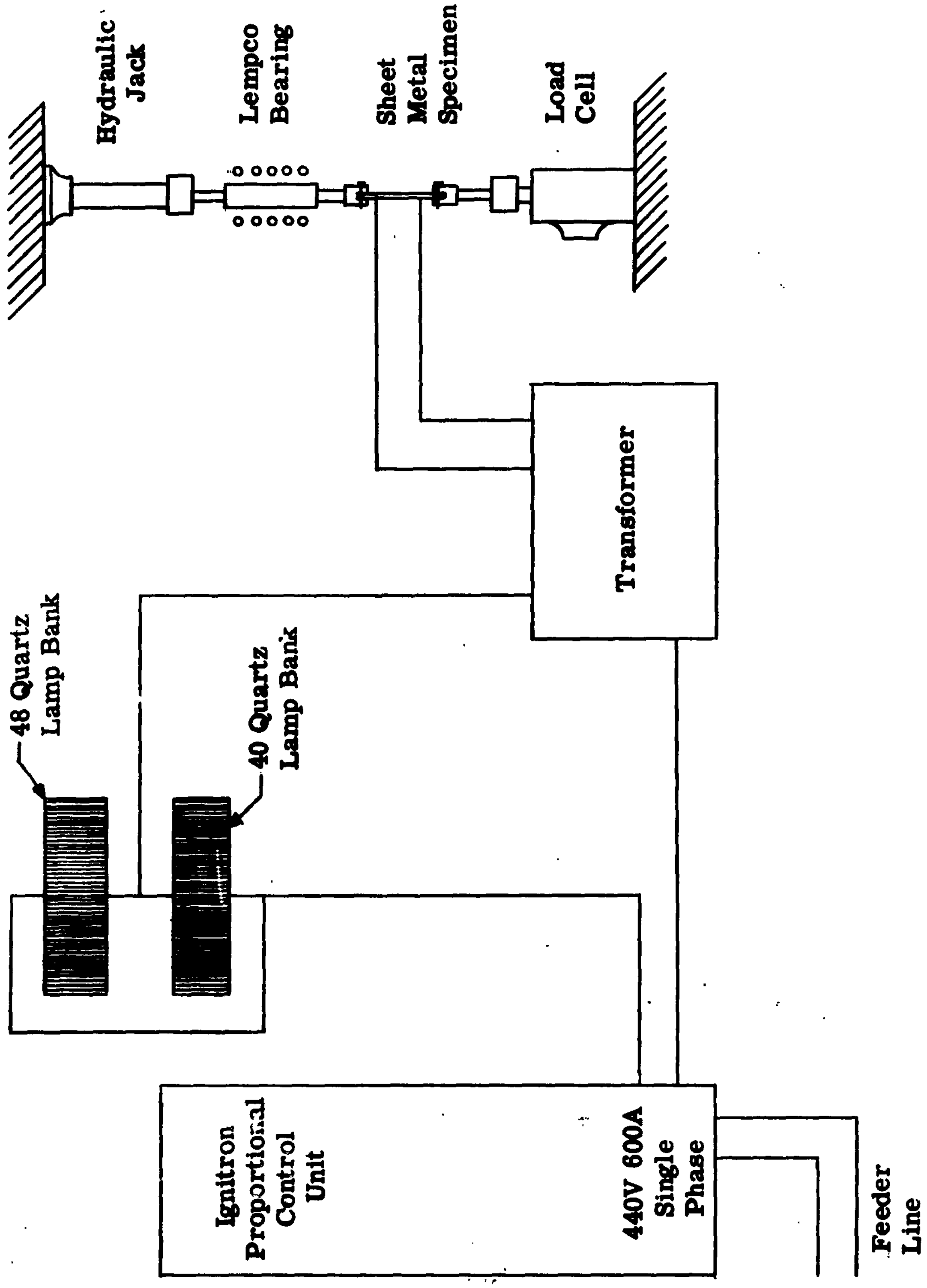


Figure 1. Block Diagram of Resistance Heating Set-up

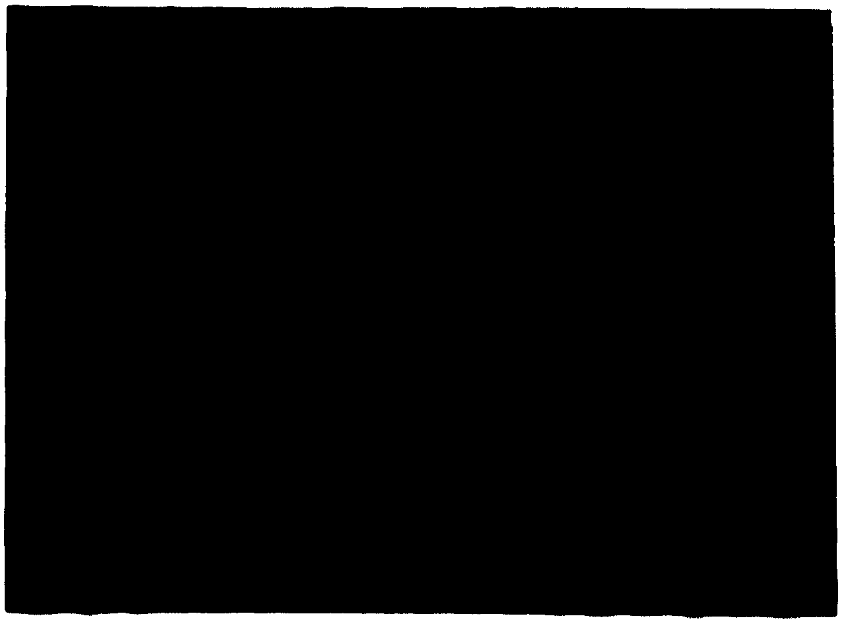


Figure 2. Westinghouse Ignitron Proportional Control Unit (All Three Control Channels Visible)

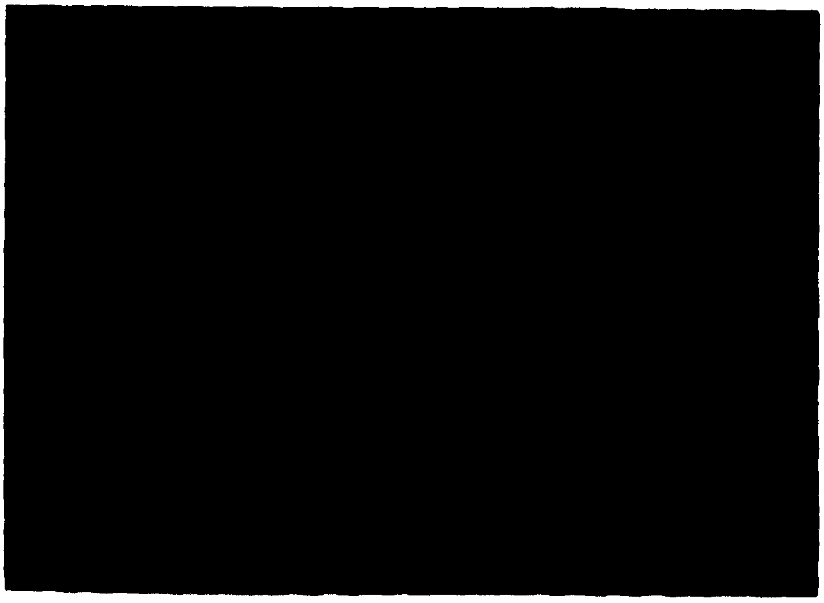
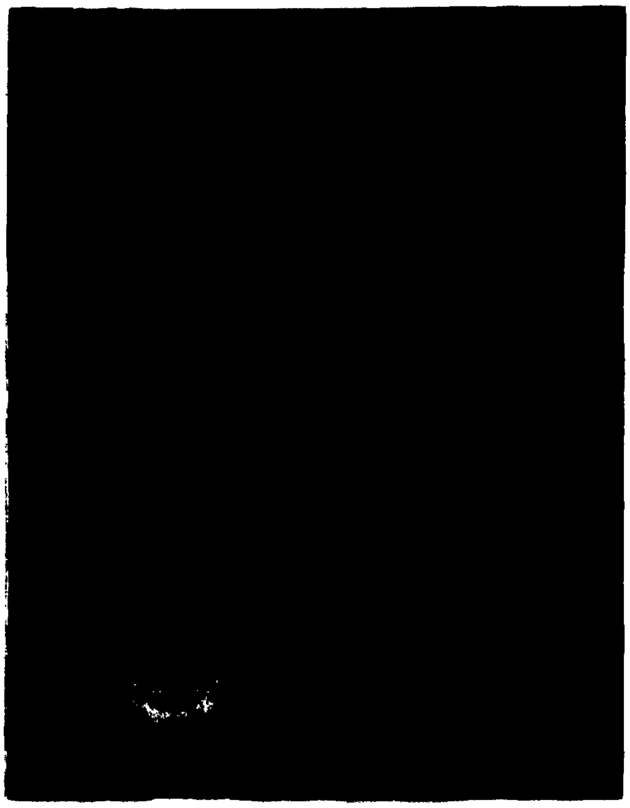


Figure 3. Resistance Load Bank of Quartz Lamps (Hoses shown are for water cooling of lamp ends and the aluminum reflector plate. Isolation transformer is visible in background)



Items shown in this photograph are:

1. Testing Frame
2. Hydraulic Load Jack
3. Tempco Bearing for Axial Loading
4. Inert Gas Exposure Chamber
5. Test Specimen
6. Load Cell
7. Leeds and Northrup Temperature Controller
8. Current Transformer
9. Ampere Meter
10. Den Point Indicator

Figure 4. Testing Frame of Resistance Heating Setup

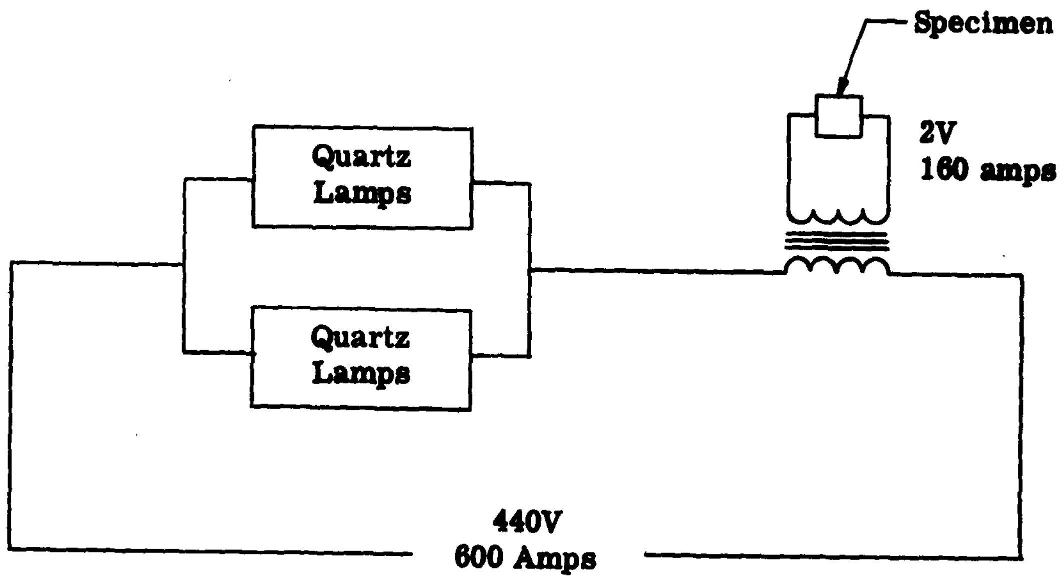


Figure 5. Electrical Schematic of Resistance Heating of a Metallic Specimen

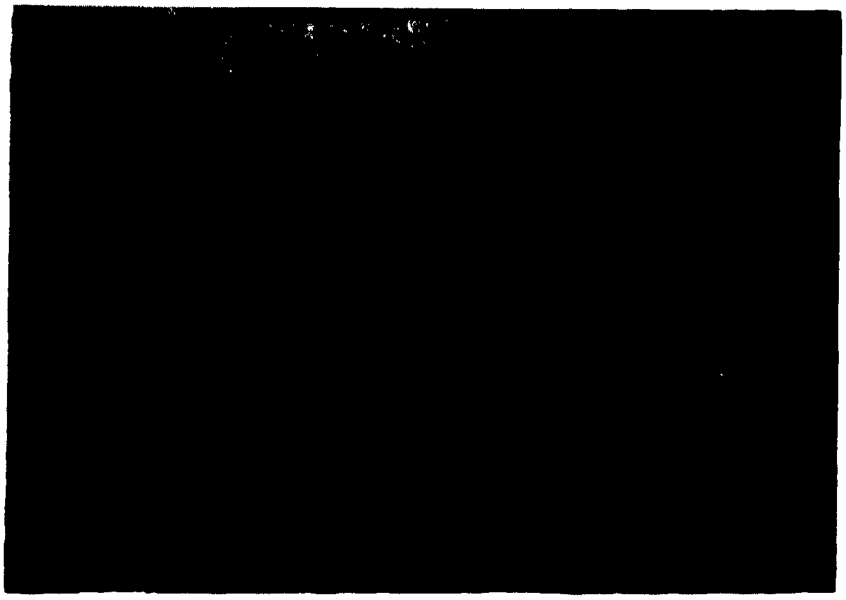


Figure 6. Close-Up of Testing Chamber Showing Electrical Anodes and Extensometer

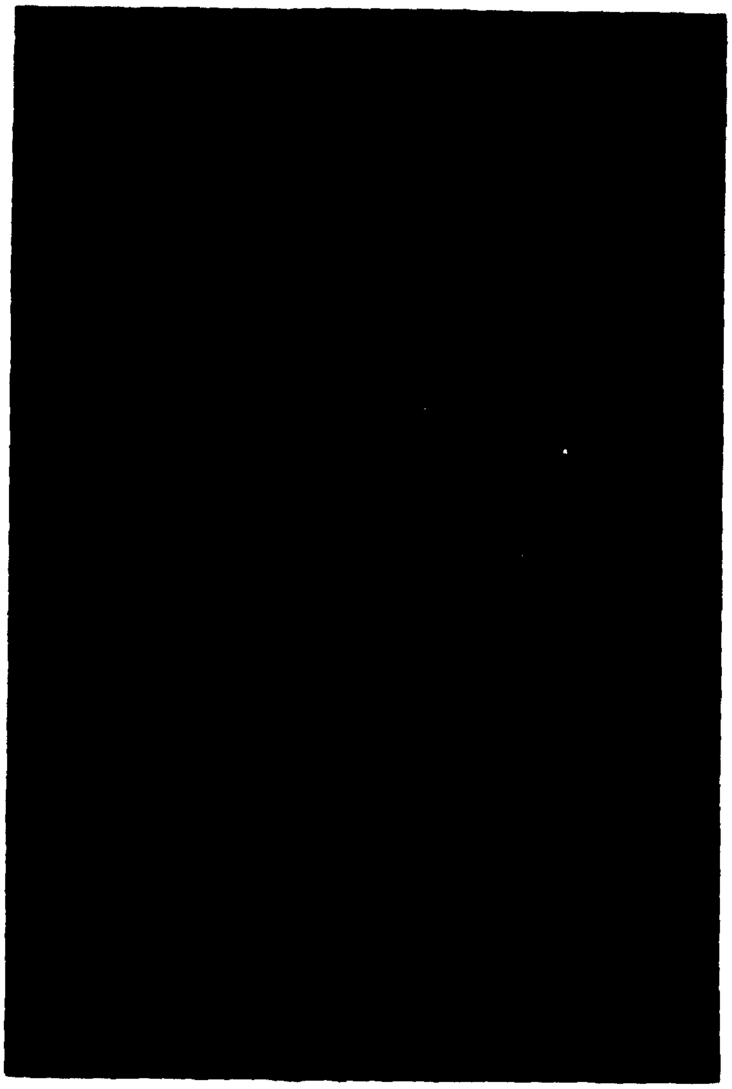


Figure 7. **Photomacrograph of Test Specimen Showing Melting of Platinum 10% Rhodium Thermocouple (thermocouple wire has rewelded itself on edge of specimen)**

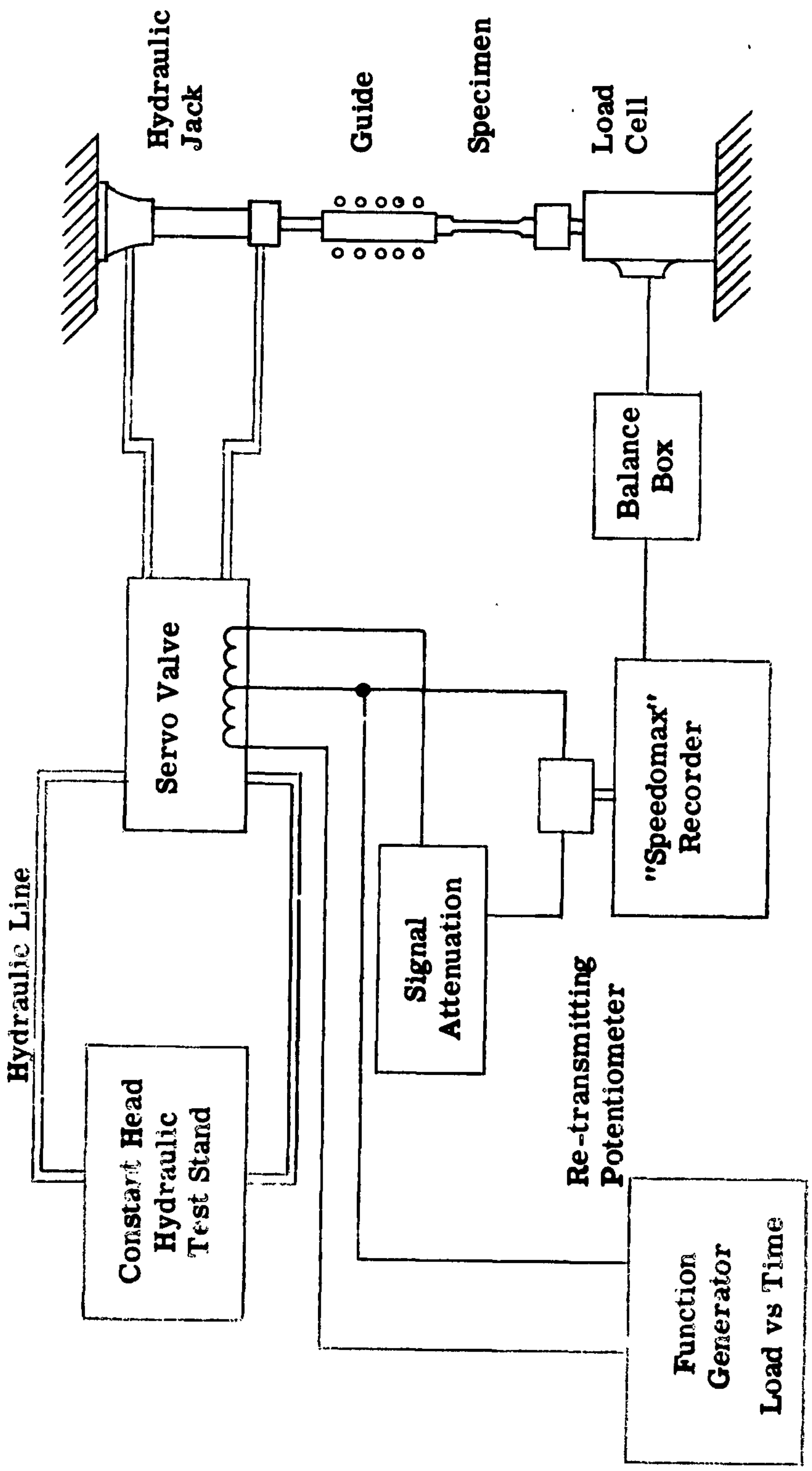


Figure 8. Block Diagram of Loading System Servo Loop

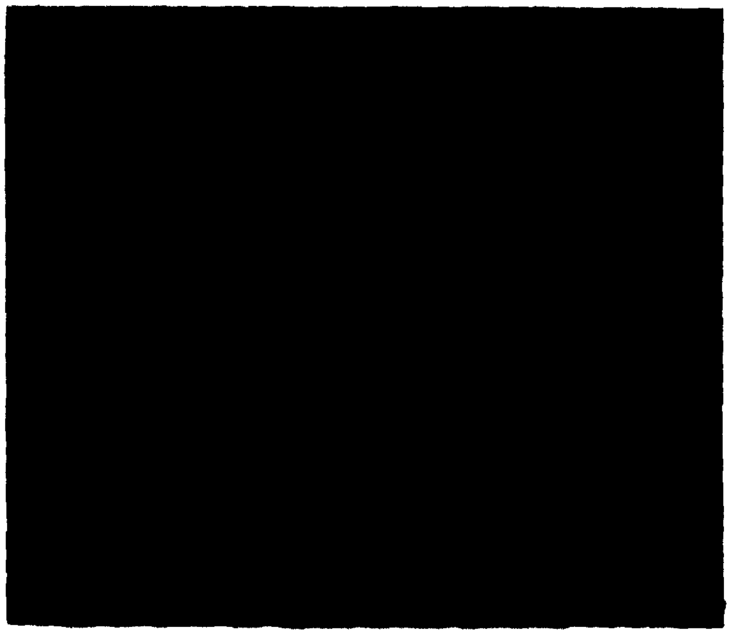


Figure 9. Sheet Bar Test Specimens with Extensometer Mounting Shoulders

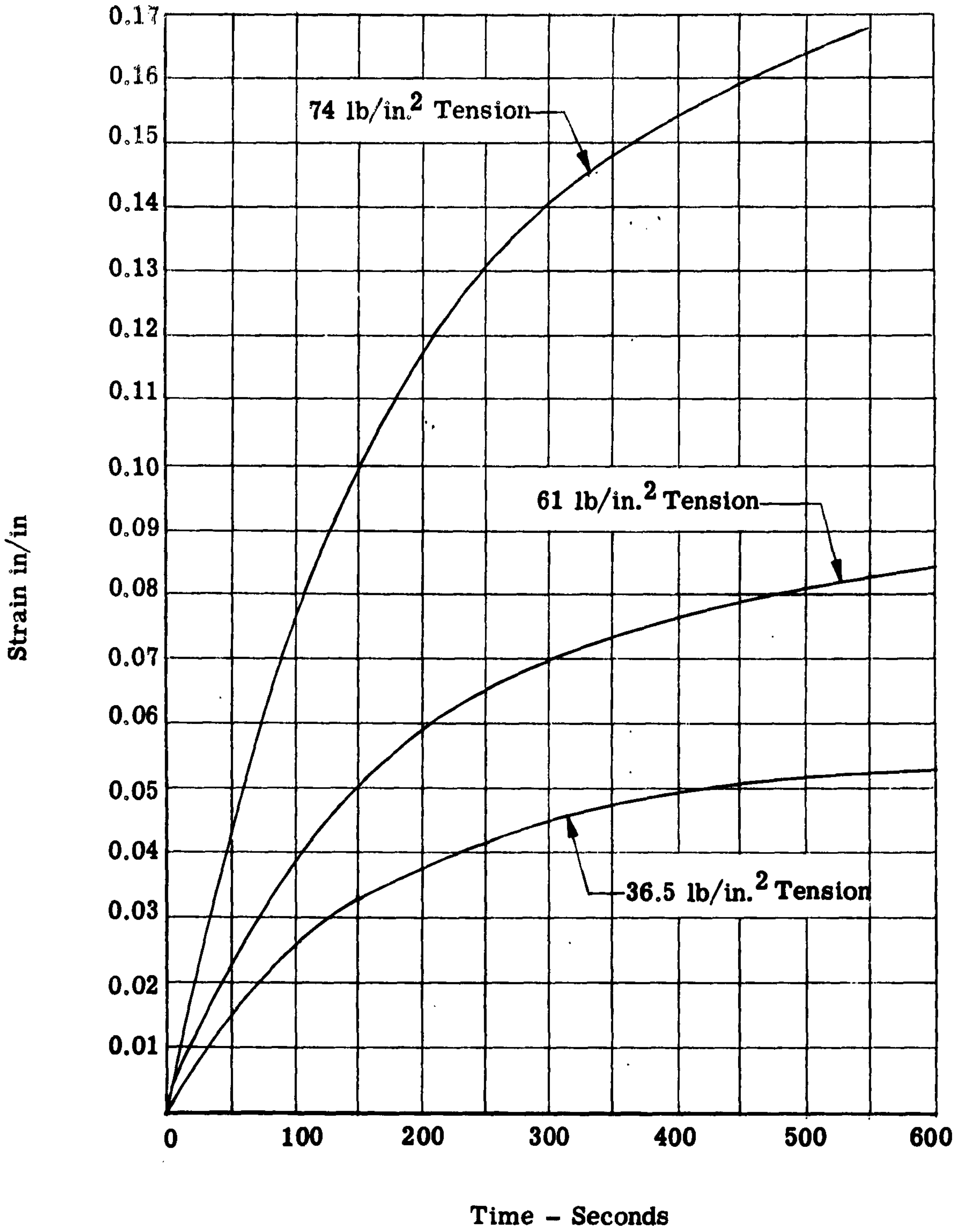


Figure 10. Creep Curves, RC-70 Titanium (2500°F)

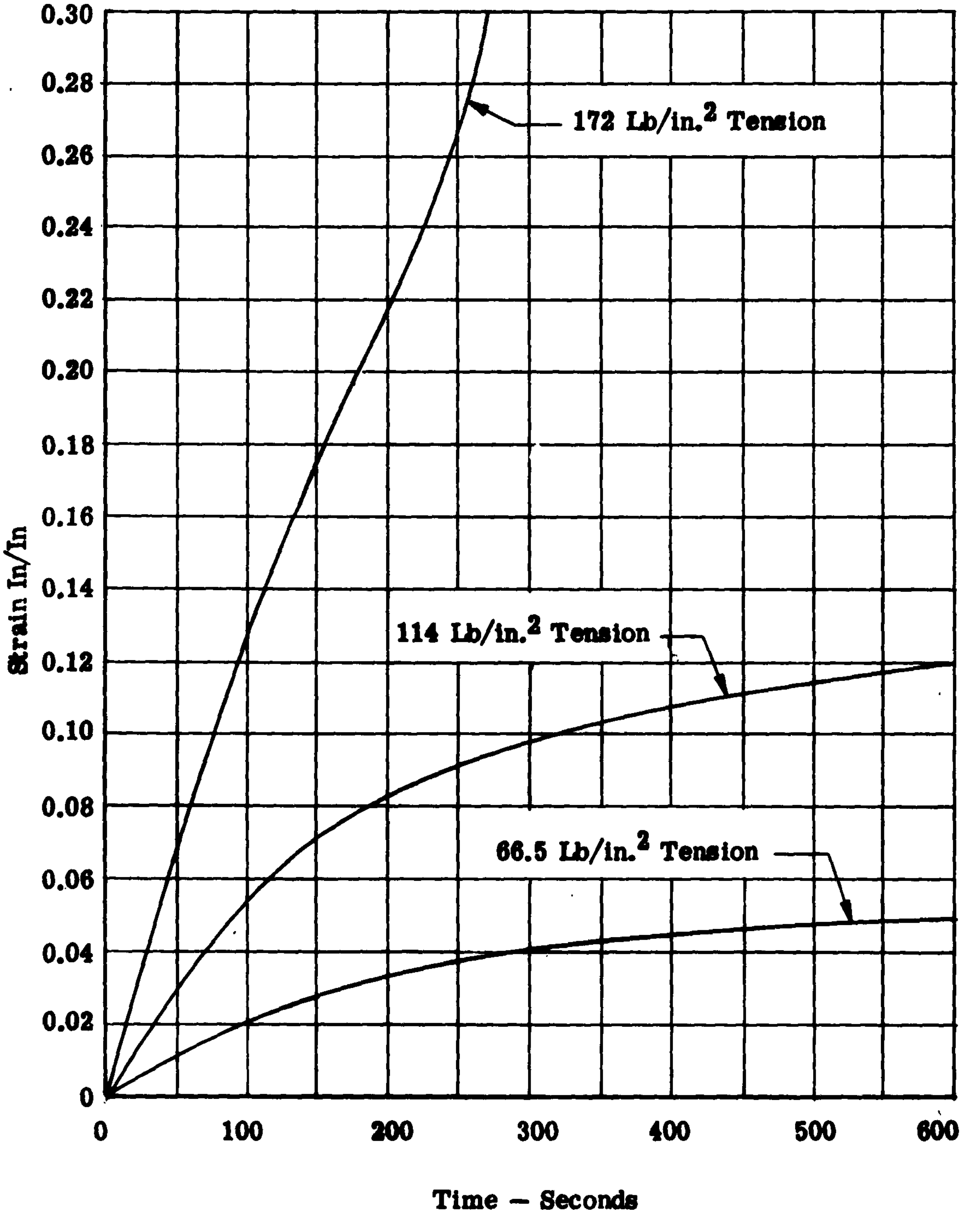


Figure 11. Creep Curves, RC-70 Titanium (2250°F)

TABLE I

SHORT TIME ELEVATED TEMPERATURE PROPERTIES OF COMMERCIALLY PURE TITANIUM

AMS 4901B - RC 70A

Specimen No.	Test Temperature	Ultimate Str.	Yield Str.	Elong. % in 2 in.
75	1800	876.0	298.0	53.0
76	1800	803.0	274.0	56.0
Average	1800	839.3	286.0	54.5
72	2000	460.0	200.0	47.0
73	2000	431.0	120.0	50.0
79	2000	479.0	168.0	50.0
Average	2000	455.0	162.7	49.0
29	2250	466.0	213.0	37.4
30	2250	312.0	128.0	40.7
31	2250	305.0	140.0	34.3
32	2250	442.0	176.0	50.0
33	2250	466.0	190.0	43.7
34	2250	468.0	190.0	50.0
80	2250	298.0	100.0	47.0
81	2250	298.0	100.0	40.0
Average	2250	381.9	154.6	42.9
1	2500	320.7	118.0	26.4
2	2500	211.4	82.0	40.0
3	2500	211.0	84.0	35.5
4	2500	184.0	71.0	40.0
5	2500	190.0	47.0	40.0
6	2500	106.0	45.0	40.0
7	2500	169.0	42.0	40.0
Average	2500	198.9	69.8	37.4

TABLE II

SHORT TIME ELEVATED TEMPERATURE PROPERTIES OF TITANIUM ALLOY 821

Specimen No.	Test Temperature	Ultimate Str.	Yield Str.	Elong. % in 2 in.
47	2250	900.0	480.0	22.2
48	2250	810.0	365.0	37.4
Average	2250	855.0	422.5	29.8
49	2000	1112.0	505.0	40.0
50	2000	990.0	600.0	40.0
Average	2000	1051.0	552.5	40.0

TABLE III

SHORT TIME ELEVATED TEMPERATURE PROPERTIES OF TITANIUM ALLOY 6A1-4Va

Specimen No.	Test Temperature	Ultimate Str.	Yield Str.	Elong. % in 2 in.
68	2000	1493.0	965.0	53.0
69	2000	1377.0	690.0	53.0
70	2000	1150.0	630.0	56.0
71	2000	1309.0	700.0	50.0
Average	2000	1332.0	746.0	53.0

TABLE IV

SHORT TIME ELEVATED TEMPERATURE PROPERTIES OF TITANIUM ALLOY B120VCA (BETA TYPE)

Specimen No.	Test Temperature	Ultimate Str.	Yield Str.	Elong. % in 2 in.
64	2000	3458.0	1800.0	36.5
65	2000	2575.0	1300.0	27.2
Average	2000	3016.0	1550.0	31.8
54	2250	1380.0	1080.0	37.8
55	2250	1200.0	670.0	18.7
56	2250	1260.0	880.0	33.8
56A	2250	1360.0	510.0	34.3
Average	2250	1300.0	782.0	31.1
200	2500	1179.0	602.0	31.0
202	2500	1359.0	795.0	34.0
204	2500	1216.0	567.0	37.5
206	2500	1154.0	590.0	34.4
Average	2500	1227.0	638.5	34.2

TABLE V

CREEP PROPERTIES OF COMMERCIALLY PURE TITANIUM

RC-70

Specimen No.	Test Temperature	Creep Stress	Elong. in 10 min. in 2 in. Gage	% of Average Yield Stress
35	2250	172.0	35.2	110.0
36	2250	66.5	5.5	44.5
37	2250	66.5	4.1	44.5
38	2250	66.5	6.8	44.5
39	2250	66.5	4.9	44.5
40	2250	66.5	5.9	44.5
41	2250	66.5	5.6	44.5
Average	2250	66.5	5.4	44.5
42	2250	114.0	30.6	73.5
43	2250	114.0	10.6	75.5
44	2250	114.0	11.2	75.5
45	2250	114.0	4.0	75.5
46	2250	114.0	15.7	75.5
Average	2250	114.0	14.4	75.1
8	2500	61.0	16.9	86.4
9A	2500	61.0	5.6	86.4
11	2500	61.0	4.6	86.4
12	2500	61.0	9.2	86.4
14	2500	61.0	6.5	86.4
15	2500	61.0	9.2	86.4
16	2500	61.0	16.8	86.4
18	2500	61.0	15.5	86.4
Average	2500	61.0	10.5	86.4

TABLE V (CONTINUED)

Specimen No.	Test Temperature	Creep Stress	Elong. in 10 min. in 2 in. Gage	% of Average Yield Stress
20	2500	36.5	5.3	51.7
21	2500	36.5	6.4	51.7
22	2500	36.5	10.7	51.7
23	2500	36.5	5.7	51.7
24	2500	36.5	7.8	51.7
Average	2500	36.5	7.2	51.7
25	2500	74.0	18.1	103.0
26	2500	74.0	13.5	103.0
Average	2500	74.0	15.8	103.0
27	2500	74.0	22.5	96.5
28	2500	74.0	21.8	96.5
Average	2500	74.0	22.1	96.5

TABLE VI

CREEP PROPERTIES OF TITANIUM ALLOY B120VCA

13% Vanadium, 11% Chromium, 3% Aluminum

Specimen No.	Test Temperature	Creep Stress	Elong. in 10 min. in 2 in. Gage	% of Average Yield Stress
57	2250	595	10.5	76.5
58	2250	595	10.5	76.5
59	2250	595	10.5	76.5
60	2250	595	10.5	76.5
61	2250	457	8.0	58.5
62	2250	457	8.0	58.5